Communication Network Design Lab
(course of Prof. Massimo Tornatore)

Lab 3

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Lab slides: courtesy of Dr. Omran Ayoub and Dr. Leila Askari

Outline

- Task #2 (RF VWP vs. RF WP)
- Elastic Optical Networks
  - Routing and Spectrum Assignment (RSA) Problem
- Heuristic Approaches
- Exercise 3.2: RSA problem *unprotected* vs. *1+1 protection*

Before starting Lab-3
Download '*LAB-3 Material*' from WeBeep

Outline

- **Task #2 (RF VWP vs. RF WP)**
- Elastic Optical Networks
  - Routing and Spectrum Assignment (RSA) Problem
- Heuristic Approaches
- Exercise 3.2: RSA problem *unprotected* vs. *1+1 protection*

Task #2: RF with *Wavelength Continuity* vs. *Without Wavelength Continuity*

- *RouteFormulationWP.java* contains some *MISSING* lines of code. Add these lines to assume wavelength continuity!

- Load the 7-nodes network topology with traffic

- Modify offered traffic per demand and set it to 3 for all demands
  - In ‘*Design tables and control window*’, go to ‘*view/edit network state*’ → ‘*Layer 0*’ → ‘*Demands*’ then select ‘Offered traffic()’, right click and click on ‘Set selected demands offered traffic’, and set it to 3

- Compare *with* and *without wavelength continuity* varying link capacity *C* = {10, 15, 20, 25}; assume k = 1, 2, 3
  - Tabulate total capacity consumption on all links with respect to *C*
    - **DEADLINE: 11/11/2022 (before next CND LAB)**

- Share pdf and code via e-mail with subject “***LAB_CND_task_2***” and name the file with your *codice persona*

Task #2: Hints

$$\min \sum_{c,n,\lambda} r_{cn\lambda} \cdot P_{cn}$$

1. Ensure you define the objective function correctly.
   - You need to ensure parameter P_{cn} (a vector) multiplies variable $r_{cn\lambda}$ (You must use a function of the type "*sum (matrix, dimension)*")
   - http://www.net2plan.com/jom/gettingStarted.php

2. In the capacity constraint: make sure that every wavelength can be used only once (you have only one fiber connecting two nodes).
   - You can set the number of wavelengths according to "linkcapacity" or similar to how you set "*k*" in line 31

3. Make sure you are considering decision variables to be integer

C	*WP* *With continuity*	*vWP* *Without Continuity*
10		
15		
20		
25		

Task #2: RF, VWP vs. WP

C	*WP* *With continuity*	*VWP* *Without Continuity*
10		
15		
20		
25		

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- **Elastic Optical Networks**
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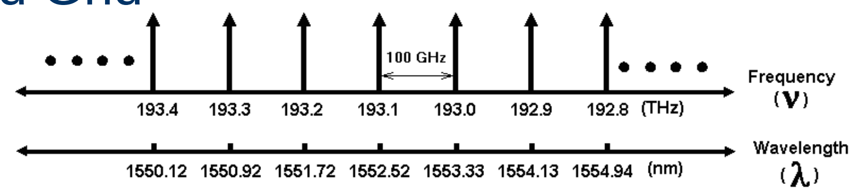
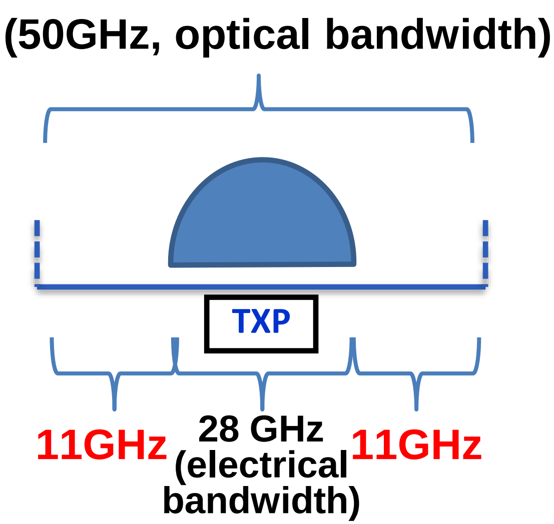
Elastic Optical Networks

- Current Wavelength Division Multiplexing grid:
  fixed channel spacing (50/100 GHz) → Fixed Grid



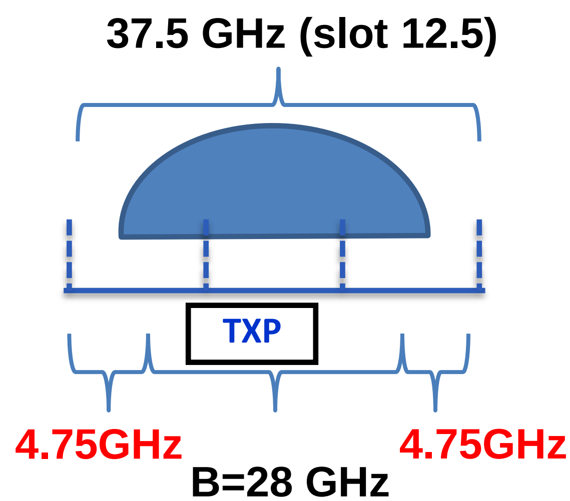
- Flexible grid (Flexi Grid): frequency slices with finer granularity (12.5 GHz)
  Increased efficiency in the usage of spectral resources



100 Gb/s = 28 GHz, 28 Gbaud

28 Gbaud are divided into:
1- 25 Gbaud → rate
With DP-QPSK:
25 GHz x 4 bit/Hz = 100 Gb/s

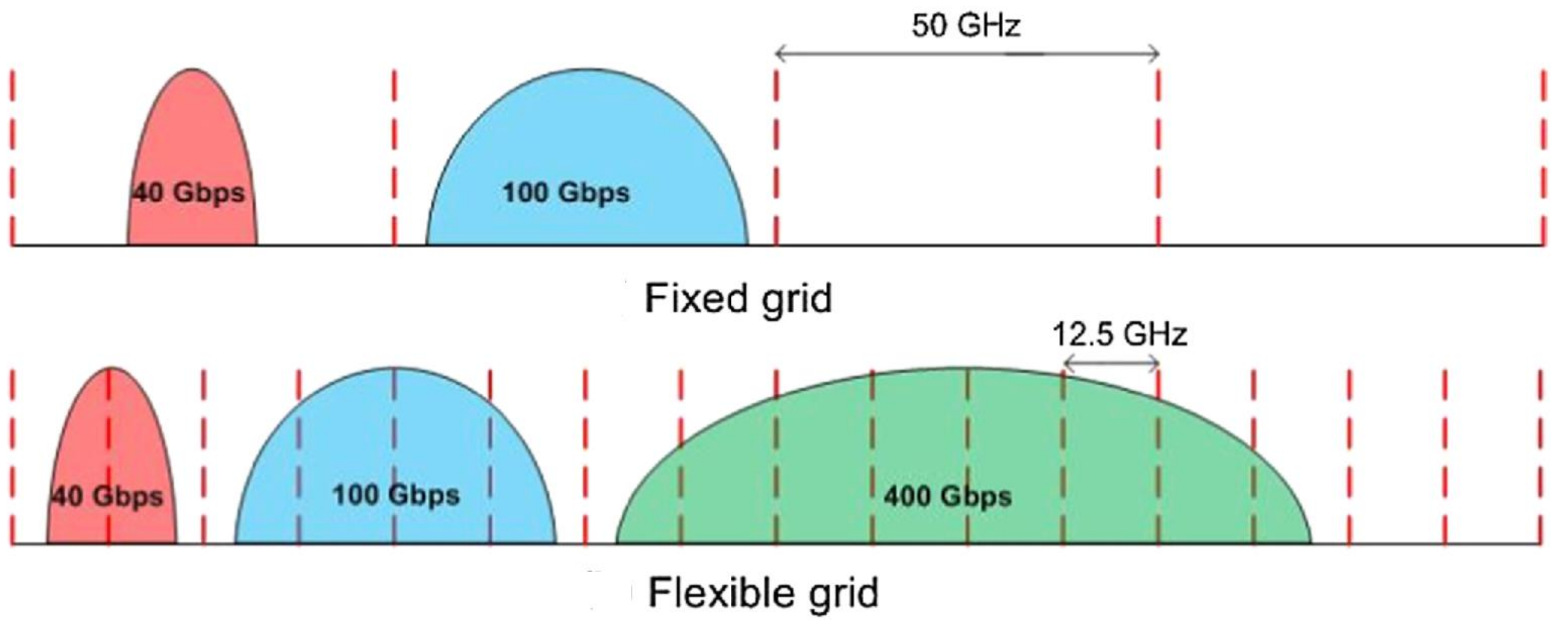
2- 3 Gbaud → FEC
(forward error correction)



Lower guardband

Elastic Optical Networks

- Fixed Grid: fixed channel spacing (50/100 GHz)
- Flexible grid (Flexi Grid): Frequency Slice Units of finer granularity (12.5 GHz)



Routing and Spectrum Assignment (RSA) instead of traditional Routing and Wavelength Assignment (RWA)

Elastic Optical Networks

- RWA vs. RSA problem

GIVEN

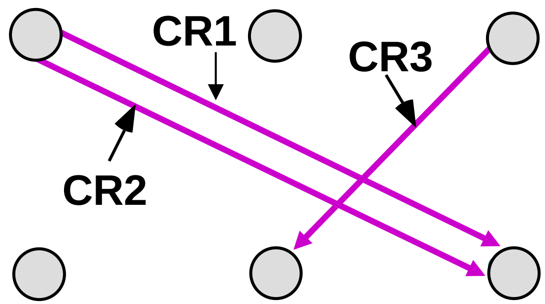
RWA:
CRs require a wavelength (50GHz spectrum)

RWA:
- **Wavelength continuity**

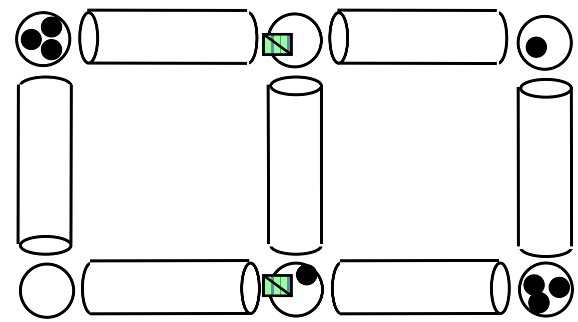
RSA:
CRs require frequency slots that are multiple of the basic frequency slice

RSA:
- ***Spectral continuity***
- ***Spectral adjacency***

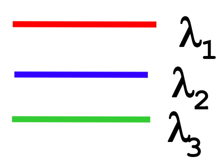
Connection requests (CR)



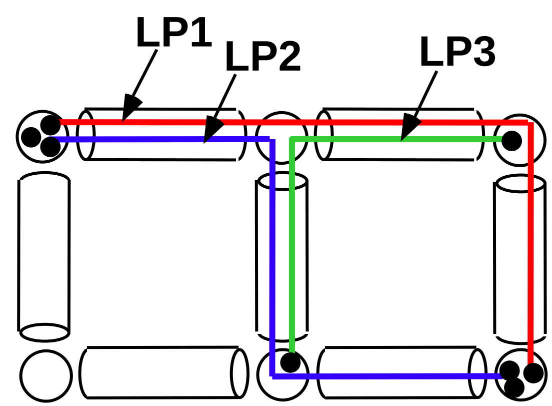
Physical topology



LP = LIGHTPATH



Optical wavelength channels



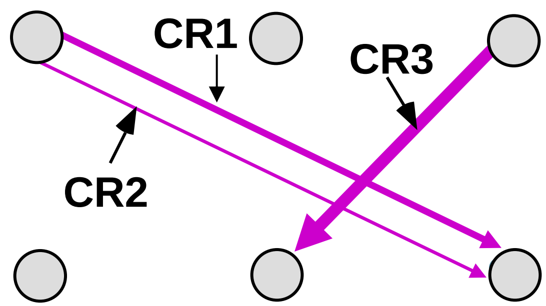
CR: Connection Request

Elastic Optical Networks: From RWA to RSA

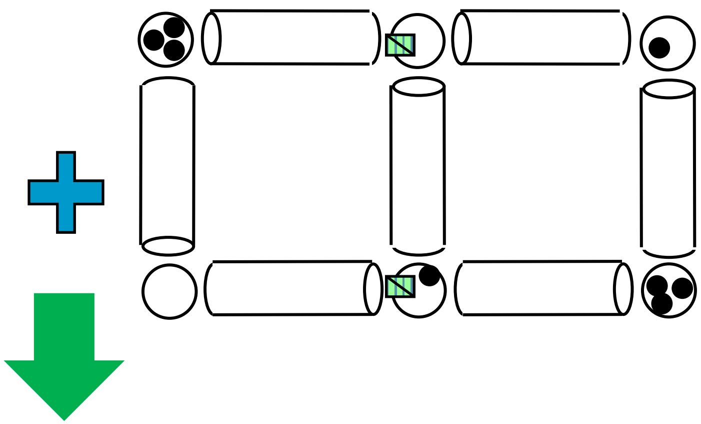
GIVEN

Now connection requests require frequency slots that are multiple of the basic Frequency Slice Unit (e.g., N x 12.5 GHz)

Connection requests



Physical topology

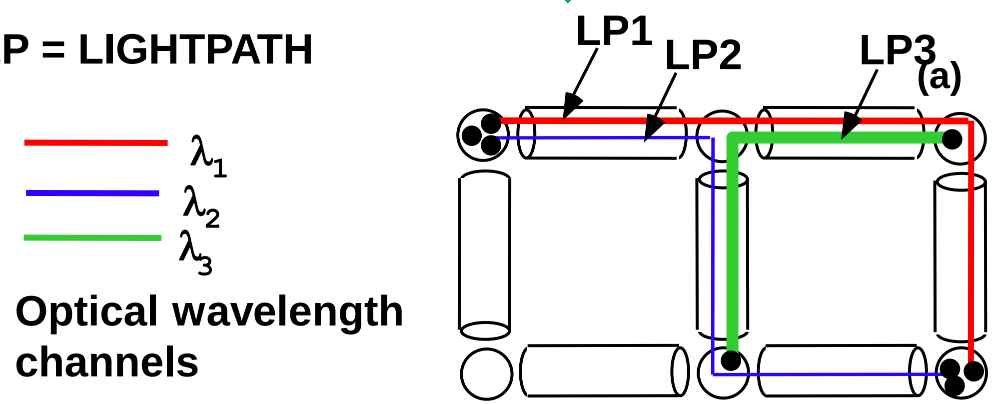


FIND RSA

Constraints:

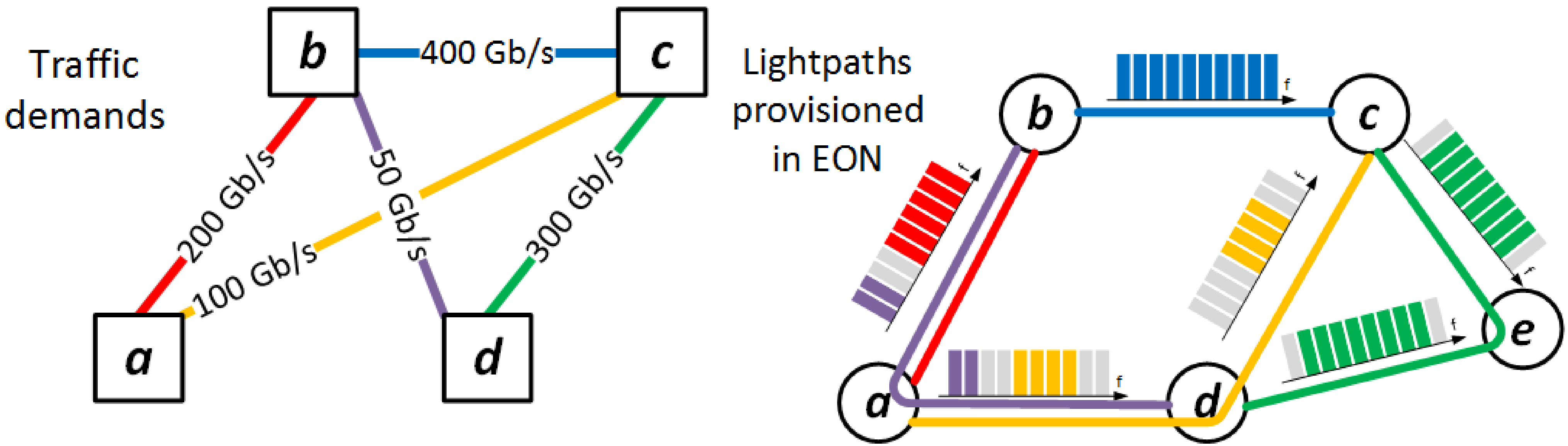
- Route the requests
- Spectrum continuity
- Spectral adjacency (continguity)
- Link capacity

LP = LIGHTPATH

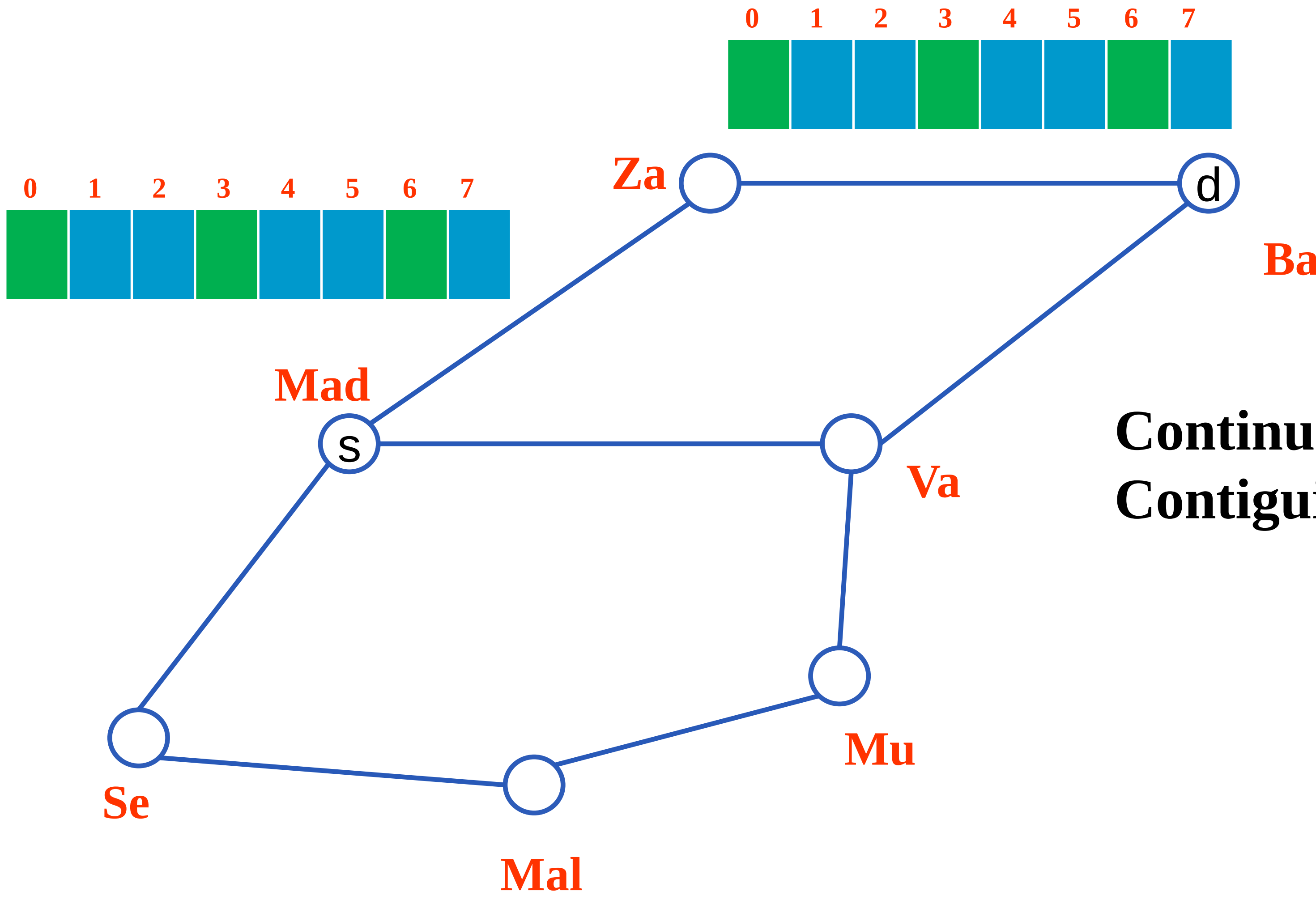


Elastic Optical Networks

- Continuity constraint: demand must use exactly the same spectrum slots in all links over which it is routed (e.g., green and purple spectrum)
- Adjacency (**contiguity**) constraint: slices assigned to a particular demand must be adjacent (contiguous)

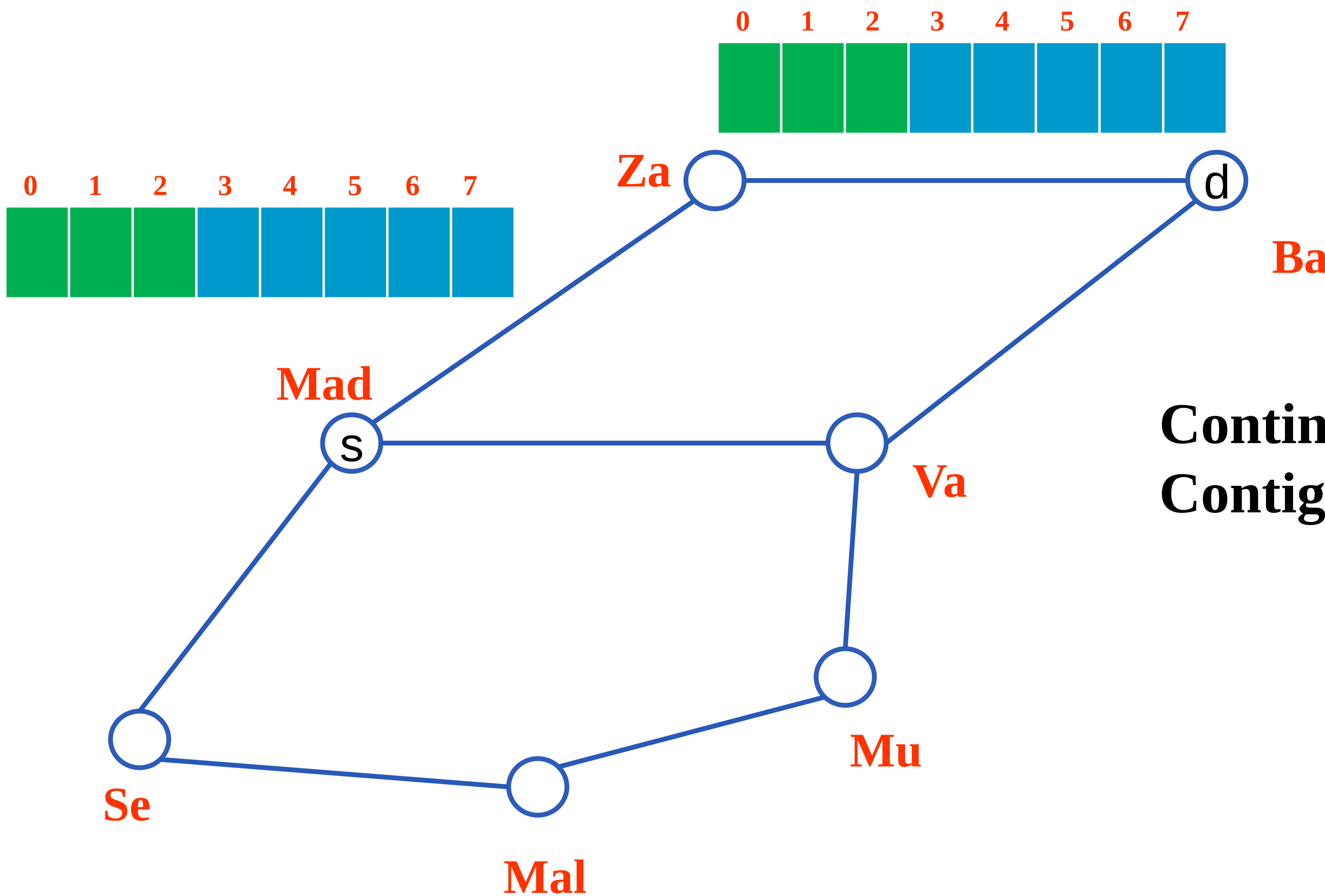


Elastic Optical Networks: spectrum continuity and contiguity constraints



Continuity constraint ✓
Contiguity constraint ✗

Elastic Optical Networks: spectrum continuity and contiguity constraints



Continuity constraint ✓
Contiguity constraint ✓

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- Task #2
- Elastic Optical Networks
  - Routing and Spectrum Assignment (RSA) Problem
- **Heuristic Approaches**
  - **Heuristic vs. ILP**
  - **Greedy heuristic approach for the RSA problem**
- Exercise 3.1: RSA problem *unprotected* vs. *1+1 protection*

Heuristic vs. ILP

- Heuristic approaches
  - Practical methods, not guaranteed to be optimal but are good enough
  - An alternative to Mathematical Programming for realistic dimension problems

- Types of Algorithms
  1. **Greedy**
  2. Local Search
  3. Meta-heuristic, e.g. Genetic Algorithms

(Example) Compare an ILP and a heuristic for RSA in two networks considering a full mesh traffic matrix
Objective: Minimize overall spectrum consumption

7-node network	ILP	Heuristic
Value of Obj. ft.	200	205
Execution time (sec)	150	2

52-node network	ILP	Heuristic
Value of Obj. ft.	NA	8000
Execution time (sec)	NA	25

Heuristic Approaches: Greedy approach

- Constructive algorithms that starts with an empty solution. A part of the solution is constructed in each iteration
  - Based on the optimization of a cost function
  - No iterative process: parts of solution already set do not change (only new pieces are added)

- Stop Conditions: When does it stop?
  - Maximum running time/iterations
    - After some fixed time, or a maximum number of iterations
  - Maximum time/iterations without improvement
    - If no improvement in the solution is observed for a finite time or number of iterations
  - Approximating an optimality bound
    - When the solution is near to the solution obtained with an approximation technique

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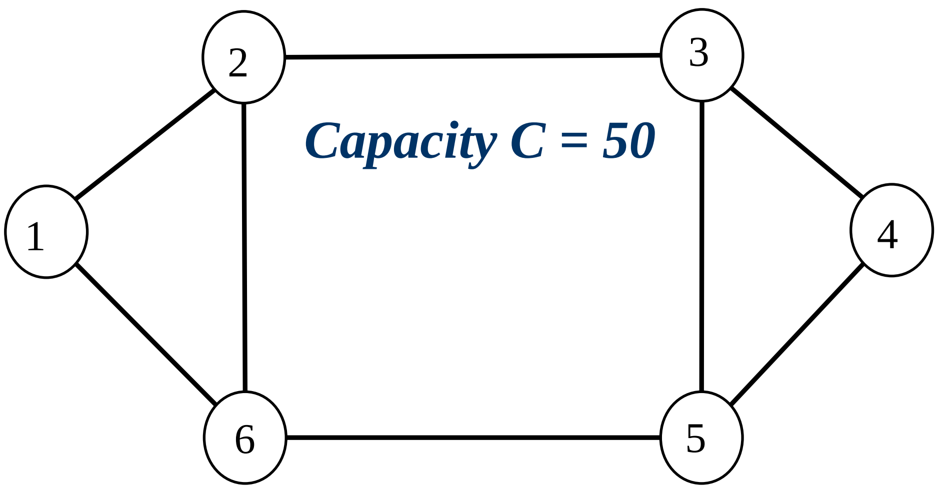
Heuristic Approaches: RSA Problem

- **Given** network topology and set of traffic demands each requesting a number of Frequency Slot Units (FSUs)
- **Decide** Route and Spectrum Assignment (RSA) for each demand
- **Objective**: minimize overall amount of carried traffic on all links
- **Subject to** RSA constraints (capacity, continuity, contiguity)

Network Topology



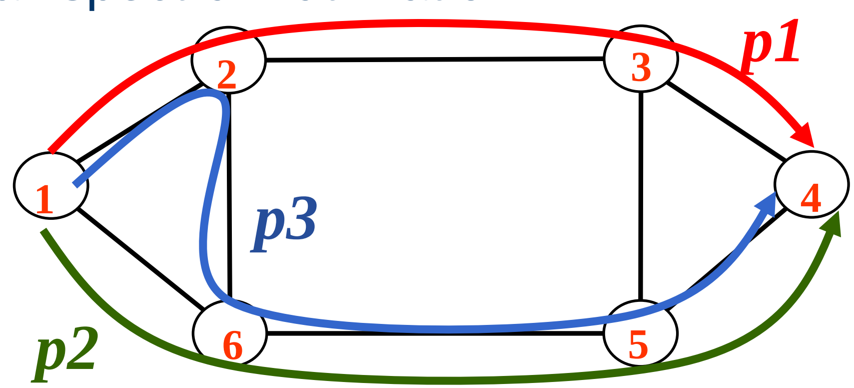
Traffic Demands

Demand id	*Src*	*Dst*	*#FSUs*
D1	1	4	3
D2	2	4	3
D3	5	1	3
D4	6	2	3
D5	3	5	6

Heuristic Approaches: RSA Problem

1. Sort demands (*in which order?)*
2. Compute candidate paths for each demand (*how many?)*
3. For each demand
   a) Sort paths in increasing order of number of links
   b) Consider the shortest path: if enough capacity, perform RSA
   Otherwise, consider next path in list
   c) Update number of FSUs available on each link used
4. Consider the next demand in the list
   a) Stop when no more demands need to be routed
5. Output RSA of each demand and overall spectrum utilization

Demand id	*Src*	*Dst*
D1	1	4



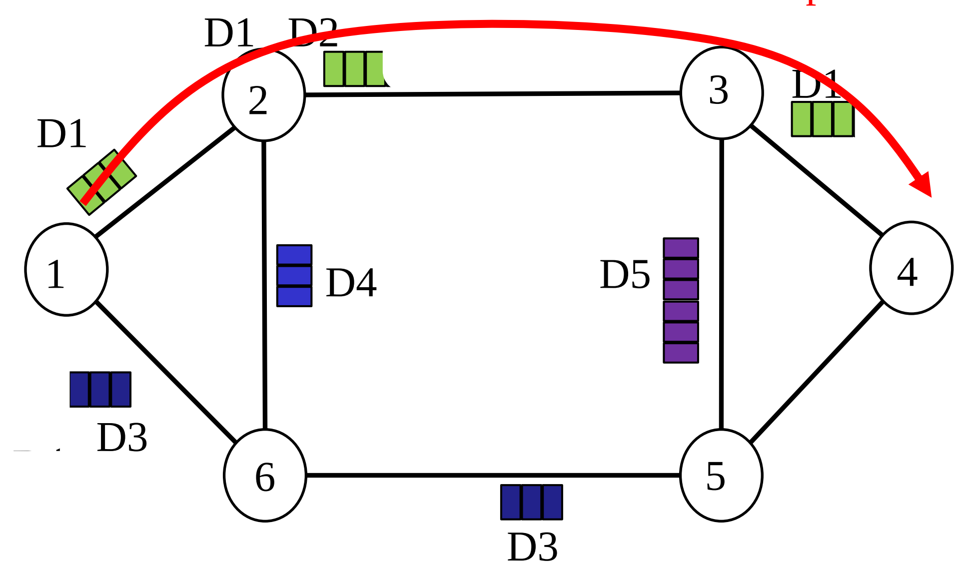
Heuristic Approaches: RSA Problem

- For each demand
  - Find best path, Route and Spectrum Allocation
  - Update number of FSUs on each fiber

id	Src	Dst	#FSUs
D1	1	4	3
D2	2	4	3
D3	5	1	3
D4	6	2	3
D5	3	5	6

Shortest path available?
If yes then route, else
check 2^{nd} shortest path

Link id	Available Capacity	Utilized Capacity
1,2	~~50~~ 47	3
2,3	~~50~~ ~~47~~ 44	6
3,4	~~50~~ ~~47~~ 44	6
5,6	~~50~~ 47	3
6,1	~~50~~ 47	3
6,2	~~50~~ 47	3
3,5	~~50~~ 44	6



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Exercise 3.1: Unprotected vs. 1+1 Protection

- Load *«Example7nodes.n2p»*

[Not the one we usually load! Make sure you load the correct file]

- Load the traffic matrix *«tm7nodes.n2p»*
- Load and run the heuristic: *«Offline_ipOverWdm_routingSpectrumAndModulationAssignmentHeuristicNotGrooming»*
  - *The .java file is in zip folder of Lab Session #3.*
- *Run algorithm once so that IP layer is shown in «View/Edit network state»*
- *Set offered traffic per demand in <u>IP layer tab</u> to 10 Gbps*
- *<u>Under settings:</u>*
  - Make sure numFrequencySlotsPerFiber (capacity) = 40
    - Spectrum resources in a fiber to serve the traffic requests
  - Other parameters as defined by defaults

Exercise 3.2: Unprotected vs. 1+1 Protection

- Run the heuristic with ‘*no protection*’ & then with ‘*1+1protection*’
  - No protection → NetworkRecoveryType: ***not-fault-tolerant***
  - 1+1 Protection → NetworkRecoveryType: ***1+1 srg-disjoint-lps***
- Consider offered traffic per demand **= 20 Gbps, 30 Gbps, and 40 Gbps**
  What is the value of the objective function?

WHY

Objective function for varying traffic and varying numFrequencySlotsPerFiber

Traffic (Gbps)	*not-fault-tolerant (no protection)*	*1+1 srg-disjoint-lps (1+1 protection)*
10	26	52
20	52	104
30	78	156
40	104	188
80	208	196

Exercise 3.2: Unprotected vs. 1+1 Protection

- What is the lowest number of frequency slots per fiber which ensures all demands are protected with 60Gbps (1+1 protection)?

numFreqSlots	*not-fault-tolerant (no protection)*	*1+1 srg-disjoint-lps (1+1 protection)*
40	156	156
50	156	240
60	156	282
70	156	310
80	156	312

  - 72!Low number of FSU -> CAN'T FULFILL THE CONSTRAINTS TO FULFILL THE DEMANDS
- What if we change the value of k? (k = 5 by default)
  - Does a higher k (e.g., k = 10) ensure a solution for 60 Gbps (1+1 protection) with a lower number of allocated frequency slots?

Exercise: Changing transponder capacity and spectrum occupancy

- "*transponderTypesInfo*": **10** 1 **1** 9600 1
  - Default: 10 1 1 9600 1 Transpoder types separated by ";" .
    Each type is characterized by the space-separated values: (i) Line rate in Gbps, (ii) cost of the transponder, (iii) number of slots occupied in each traversed fiber, (iv) optical reach in km (a non-positive number means no reach limit), (v) cost of the optical signal regenerator (regenerators do NOT make wavelength conversion ; if negative, regeneration is not possible)

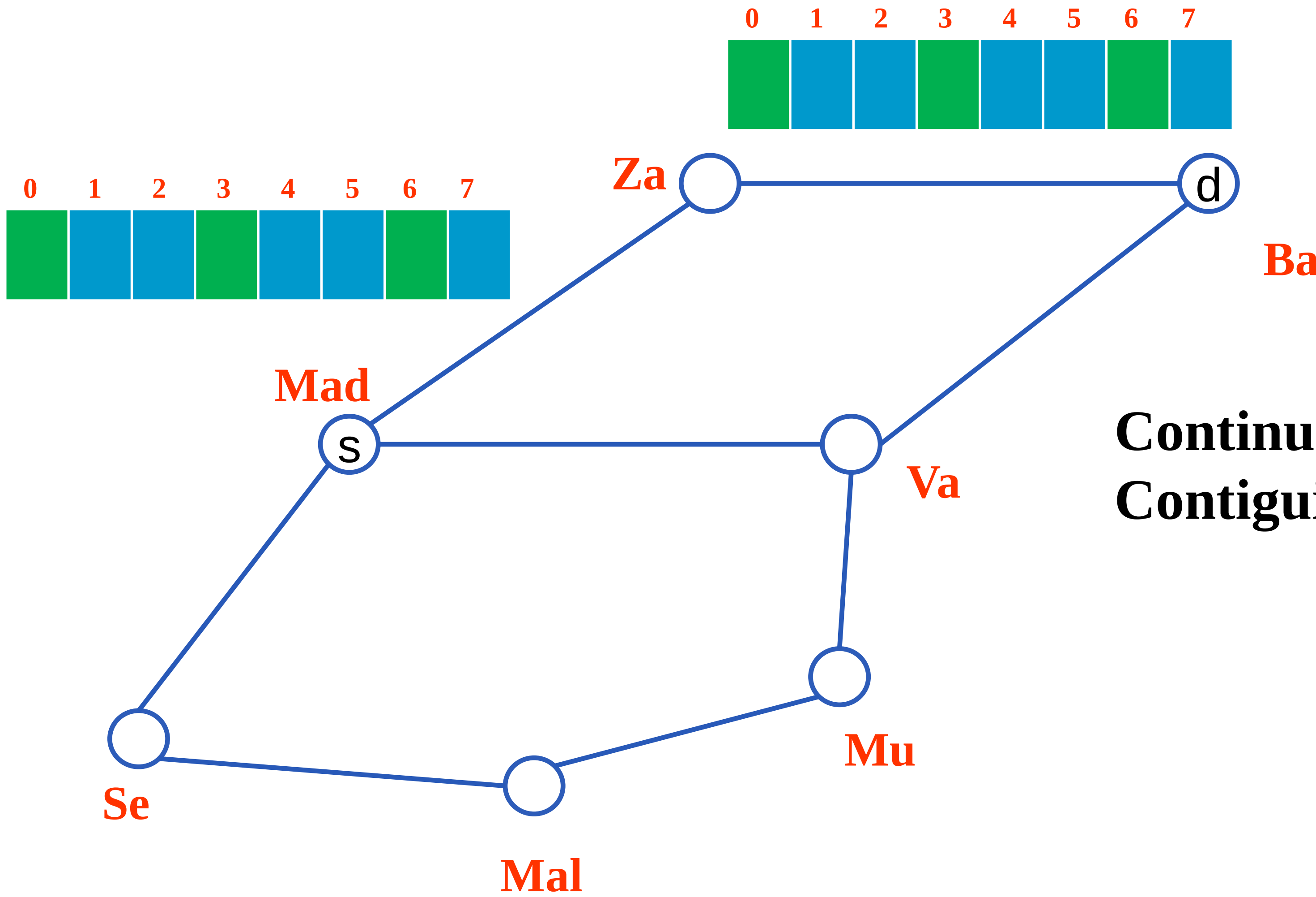
- Set offered traffic to 30 Gbps; numFreqSlots = 40

  a) If number of slots for each transponder is one (default) – can we ensure the contiguity constraint?
     - E.g., "*transponderTypesInfo*": 10 1 1 9600 1

  b) What if we modify the number of slots for each transponder – is there any difference compared to previous case?
     - E.g., "*transponderTypesInfo*": 30 1 3 9600 1

Exercise: Changing transponder capacity and spectrum occupancy

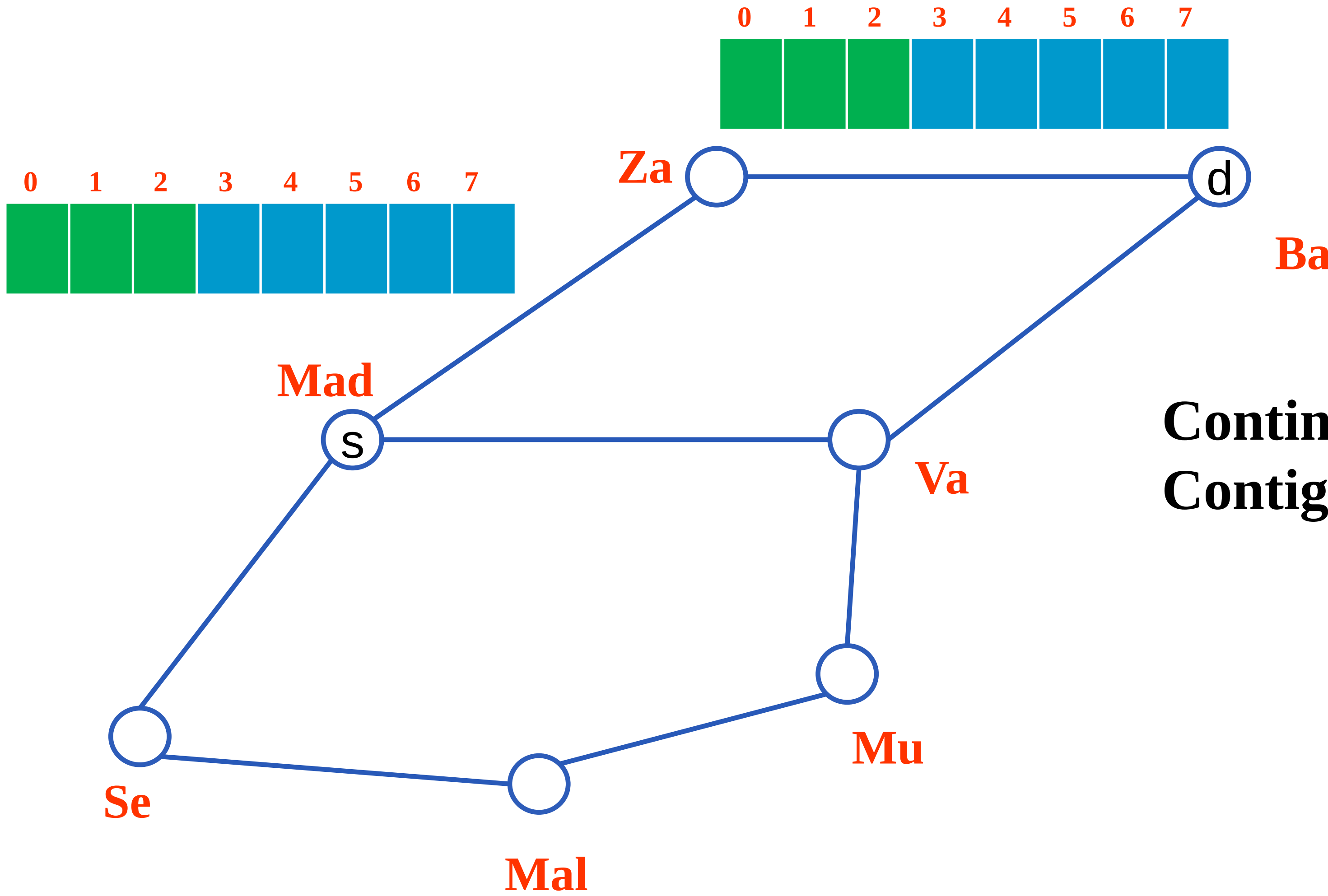
"*transponderTypesInfo*": 10 1 1 9600 1



Continuity constraint ✓
Contiguity constraint ✘

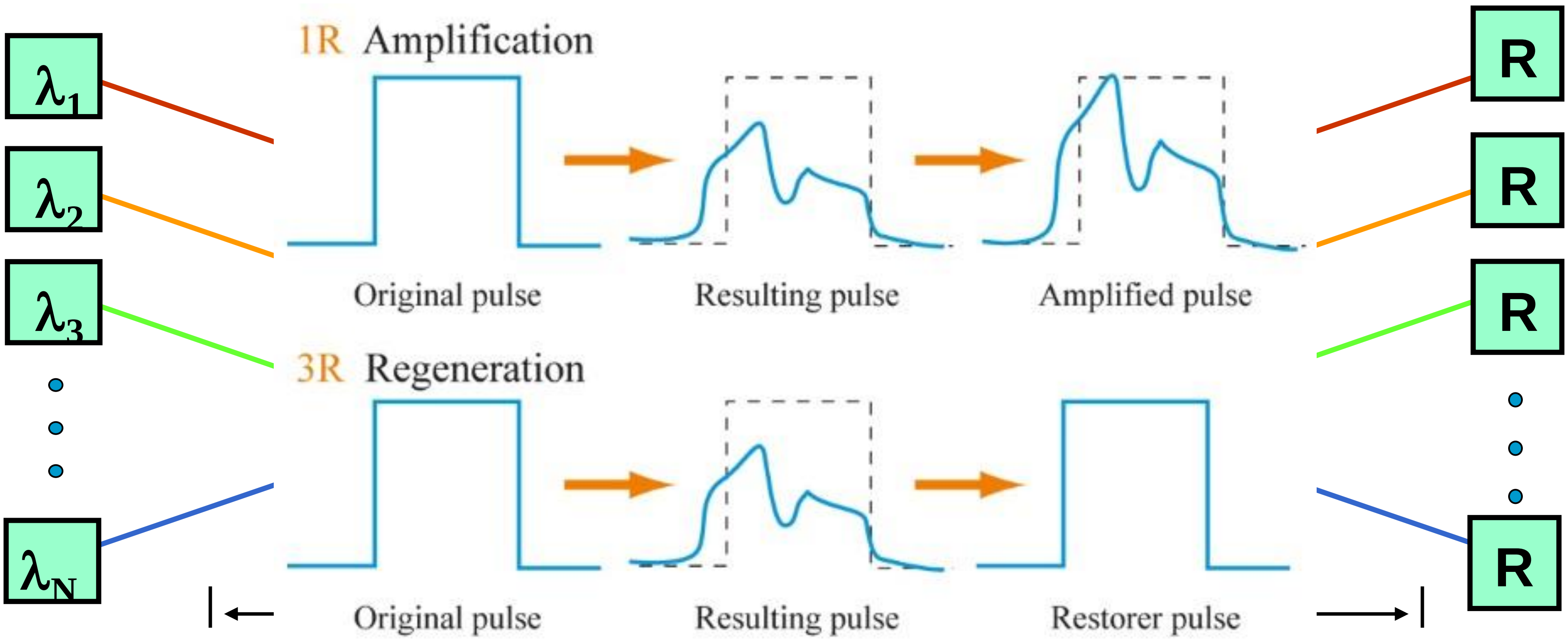
Exercise: Changing transponder capacity and spectrum occupancy

"*transponderTypesInfo*": 30 1 3 9600 1



Continuity constraint ✓
Contiguity constraint ✓

Amplification and 3R-regeneration

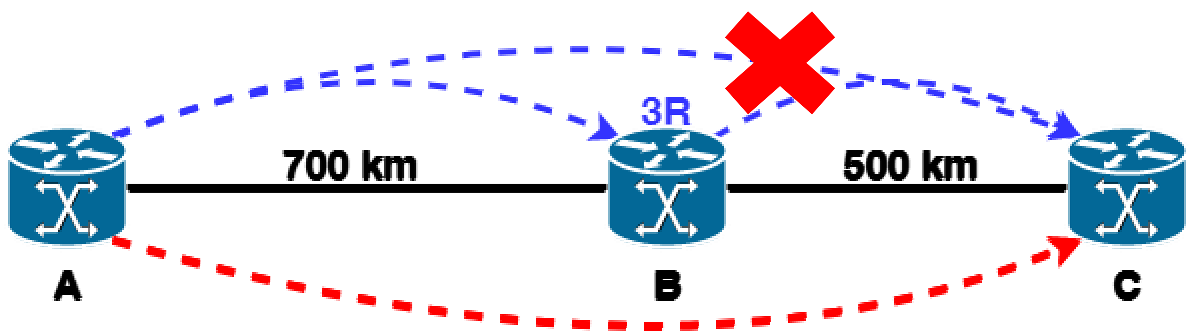


- In general signal regeneration can be 1R, 2R or 3R
  - Pulse re-amplification, re-shaping, re-timing
    - Optical amplification is 1R
- When should the signal be re-generated? How can we know?!

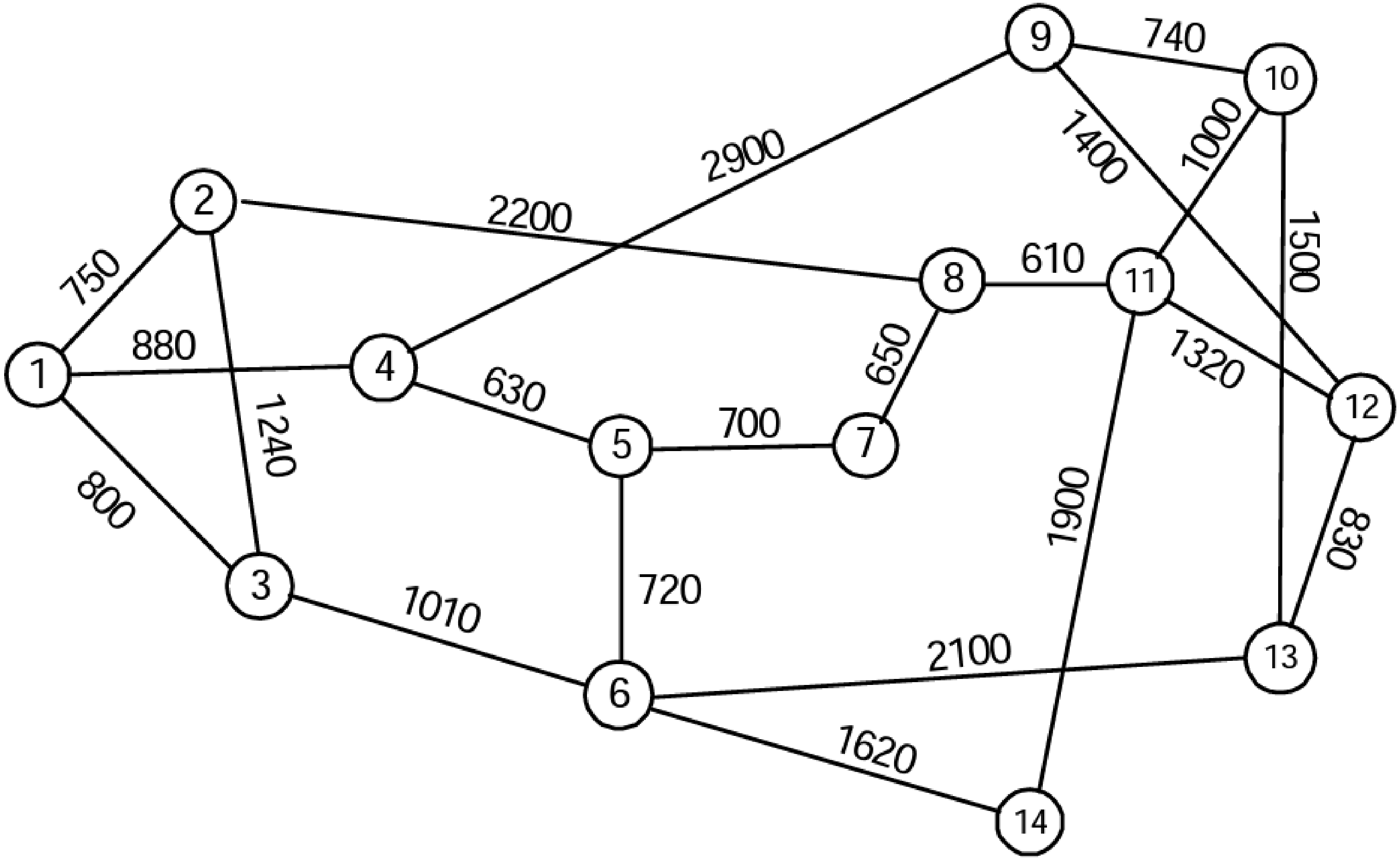
Amplification and 3R-regeneration

Data Rate (Gb/s)	Modulation format	Bits/symbol (Gb/s) - Entropy	Channel spacing Δf (GHz)	Reach (km)
800	PCS 64 QAM	5.67	100	150
700	PCS 64 QAM	5.00	100	400
600	16 QAM	4.00	100	700
500	PCS 16 QAM	3.60	100	1300
400	PCS 16 QAM	3.00	100	2500
300	PCS 16 QAM	2.39	100	4700
300	64 QAM	6.00	50	100
200	16 QAM	4.00	50	900
100	QPSK	2.00	50	3000

R1: (A, C) 100 Gb/s, QPSK **R2: (A, C) 200 Gb/s, 16-QAM**



Amplification and 3R-regeneration



- Route traffic between each-node pair and minimize number of 3R regeneration sites